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Abstract

Energy savings among households are important energy problems in Japan. After the Great East Japan earthquake in March 2011, nuclear power plants were forced to cease operations. We Japanese have worried about electricity shortages and have been requested to save electricity usage in case of a sudden outage. To avoid electricity shortages, energy savings are needed.

For energy savings, energy-saving appliances such as air conditioners and refrigerators should be promoted among households. I analyzed the conditions that households purchase energy-saving appliances by a conjoint analysis. As the conditions, an annual electricity bill, CO_2 emissions, a stable electricity supply, subsidies, the initial cost of purchasing and energy sources which generate electricity are considered. A random parameter logit model and a nested logit model were used for estimation.

To promote renewable energy such as solar and wind power is another important energy problem to solve electricity shortages and to reduce greenhouse warming-effect gases such as CO_2.

I focus on the relation between the preferences for renewable energy and the purchasing behavior of energy-saving appliances. If households purchase energy-saving appliances by using renewable energy, the problem of promoting renewable energy and energy savings could be solved simultaneously.

The estimation results indicated that households largely respond to an annual electricity bill, an initial cost and subsidies, which are monetary factors. In addition, non-monetary factors such as CO_2 emissions and a stable electricity supply also might give incentives for households to purchase energy-saving appliances. Regarding to energy sources, if renewable energy is used as a main energy source in the electricity generation, they tend to purchase energy-saving appliances.

Key words: energy saving, conjoint analysis, renewable energy
JEL Classification: C25, L51, L94, L95, Q28

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Conjoint analysis of Japanese households' purchase behavior of energy-saving appliances: the role of renewable energy[2]

1. Introduction

Energy savings are the important energy problems in Japan. After the Great East Japan earthquake in March 2011, due to the serious accidents of nuclear power plants in Fukushima prefecture, nuclear power plants were forced to cease operations. People who live in Kanto area around Tokyo experienced planned power outages because of electricity shortages from the stop of nuclear power plants. We Japanese have worried about electricity shortages especially at times of peak of demand in summer and winter and have been requested to save electricity usage in case of sudden outages. Electricity shortages will continue until nuclear power plants start operation. To avoid electricity shortages, energy savings are needed. Climate change is also one of the reasons to save energy. If we reduce electricity usage, we reduce global greenhouse gases (GHG) such as CO_2.

As one of the solutions of energy savings, energy-saving appliances air conditioners and refrigerators should be promoted among households. I analyze the conditions that households decide to purchase energy-saving appliances. Sometimes, the governments give subsidies to households when they purchase energy-saving appliances.

As the conditions, an annual electricity bill, an initial cost in purchasing, subsidies, CO_2 emissions, a stable electricity supply, and energy sources which generate electricity are considered. An annual electricity bill, an initial cost and subsidies are monetary factors, while CO_2 emissions, a stable electricity supply and energy sources are non-monetary factors. I focus on non-monetary factors as well as monetary factors. If an annual electricity bill and an initial cost are reduced, households may purchase energy-saving appliances. More subsidies give incentives for households to purchase them. If CO_2 emissions are reduced, they might purchase such appliances. They will choose energy-saving appliances when a stable electricity supply is secured.

Especially, I focus on the role of energy sources which generate electricity. I examine the relation with the preferences for renewable energy and the purchasing of energy-saving appliances. Households might purchase energy-saving appliances if renewable energy such as solar and wind power is used in the electricity generation.

To promote renewable energy is another important energy problem. After the earthquake, Japan has relied on fossil fuels such as oil, natural gas (LNG) and coal. However, fossil fuels emit GHG such as CO_2. Instead of nuclear power and fossil fuels, renewable energy should be promoted as alternatives. To promote renewable energy, the Japanese government introduced a feed-in-tariff system in July 2012. Moreover, the Japanese government published the desirable composition of energy sources called the "best-mix" in fiscal year 2030 as an energy plan[3]. This plan states that the share of renewable energy will be raised to around 22–24%. However, despite the feed-in-tariff system, the share of renewable energy except water power is only 3.2%[4].

Accordingly, to promote renewable energy and energy saving should be Japan's official energy policy. To promote renewable energy, the penetration of photovoltaic panels and wind generators among households is essential. If households that support renewable energy tend to purchase energy-saving appliances, these two problems could be solved simultaneously.

Kinoshita (2016) used a conjoint analysis to reveal a high willingness to pay (WTP) for renewable energy sources such as solar and wind power. Kinoshita (2017) then clarified the factors that lead households to reduce electricity usage. One of the factors was energy sources

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[3] The Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry

[4] The Federation of Electric Power Companies of Japan

used in electricity generation. However, I couldn't find the clear relation between energy sources and saving behavior. The present paper revises the previous work and makes clear the relation between households' preference for renewable energy sources and their energy-saving behavior as an extension of those studies.

In the short-term, energy saving can help avoid the tightness of electricity demand and supply, whereas in the long-term energy saving can help alleviate global warming and long-term energy shortage problems. I consider the long-term energy saving.

This paper is consisted of the following section. In section 2, related literature is introduced. In section 3, conjoint analysis and profiles are illustrated. In section 4, econometric methods are explained. In section 5, estimation results are presented. In section 6, conclusions and policy implications are suggested.

2. Related literature

There are many studies that households purchase energy-saving appliances. I introduce some of them. Nakagawa et al. (2013) analyzed the preferences for energy-saving appliances among households in Japan by a conjoint analysis. They noted the liquidity constraint problem as the reason households don't purchase energy-saving appliances, i.e., these appliances are very expensive. They analyzed that subsidies and payment frequency (split payments) helped households to purchase such appliances. They found that subsidies and split payments have significant effects on the purchase of such expensive appliances. They treat with only monetary reasons and don't treat with non-monetary reasons such as CO_2 emissions and energy sources. Mizobuchi and Takeuchi (2016) examined repurchases and additional purchases of energy-saving appliances among Japanese households through a field experiment. Households who purchase an energy-saving air conditioner can save more electricity than households who don't purchase this type of appliance. Households who purchase an additional energy-saving air conditioner can save more electricity, whereas households who repurchase an energy-saving air conditioner don't save additional electricity. Revelt and Train (1998) estimated the households' preferences for high efficiency appliances using a random parameter model. Revealed preference method was used, not stated preference method. They found that households need rebates and a loan when purchasing high efficiency appliances. Ida et al. (2014) estimated the preferences for smart meters, solar panels, and electric cars among Japanese households via conjoint analysis. They calculated WTP for such equipment. Scarpa and Willis (2010) referred to appliances related with renewable energy. They estimated the preferences of UK households for renewable energy technologies using conjoint analysis. They found that households represented high WTP for micro generation technologies such as solar photovoltaic, micro-wind and so on. However, the value was not so large to cover the higher initial costs.

In the investment of energy-saving appliances, an energy efficiency gap is often discussed[5]. Due to externalities, the investment inefficiency is caused. To avoid this problem, some policies such as subsides are needed. However, I suggest that this problem will be solved by their preferences for renewable energy.

Next, I introduce some studies about households' preferences for renewable energy sources. Morita and Managi (2013) used conjoint analysis to estimate preferences for energy sources, particularly renewables, after the earthquake in 2011. They estimated the WTP for each energy source and suggested policy implications vis-à-vis the Japanese government's energy mix. They obtained negative WTP for nuclear power, but positive WTP for renewable energy sources such as solar and wind power. Murakami et al. (2015) estimated consumers' WTP for renewable energy and nuclear energy in the US and Japan. They used conjoint analysis, and consumers in both countries showed negative preferences for nuclear power and positive preferences for renewable

[5] Allcot and Greenstone (2012) estimates an energy efficiency gap and suggests some policy implications.

energy.

I analyze the conditions that households purchase energy-saving appliances. Especially, I focus on the role of energy sources used when electricity is generated. If the energy source is renewable energy, households who support renewable energy might purchase energy-saving appliances. In other words, they need energy-saving appliances with solar panels or wind generators. There are many studies about purchasing behavior of energy-saving appliances and preferences for renewable energy. However, they don't mention the relation though these two problems are necessary in Japan.

3. Conjoint analysis

I use a conjoint analysis to analyze households' preferences for energy-saving appliances[6]. Conjoint analysis is one of the stated preference methods (SPM) to analyze the individual choice for several alternatives under future and hypothetical conditions. Individual preferences can be estimated for hypothetical goods or services which have several attributes. We present some alternatives and respondents choose one alternative of the hypothetical goods or services. In this paper, three alternatives are presented to households and they choose the most preferred one. Sometimes, the goods or services have not yet prevailed, and this method is often used in marketing research. I analyze households' preferences for energy-saving appliances which have hypothetical attributes and conditions. The energy-saving appliances have several attributes such as initial costs and the levels of these attributes change. The researcher decides the number of attributes and their levels to make profiles. A profile that has few attributes is not enough to describe a good object of study, but a profile with too many attributes makes it difficult for respondents to choose among options. In general, five or six attributes are suitable. After attributes and their levels are selected, their profiles are completed. However, if all the combinations of attributes and levels are adopted, the patterns are too large and cause strong correlation between some attributes, which is called multicollinearity. To avoid these problems, profiles are created by the orthogonal planning method. From various cards that we obtain through the orthogonal planning method, selecting cards and their combinations, profiles are made after deleting unrealistic and dominant cards. I used *SPSS* conjoint version 17.0 for the orthogonal planning.

Contingent Valuation Method (CVM) is another popular stated preference method, but it is not a choice experiment. CVM can be used to evaluate users' valuation of non-marketable targets such as forests and beaches. CVM evaluates the value of one target and doesn't evaluate the value of each attribute.

I presented the following three alternatives to households in the questionnaire.

Alternative 1: Status Quo: Households don't purchase any energy-saving appliances.
Alternative 2: Energy-Saving Program A: Households purchase energy-saving appliances.
Alternative 3: Energy-Saving Program B: Households purchase energy-saving appliances.

When households choose alternative 1, they don't purchase any energy-saving appliances. When households choose alternative 2 or 3, they purchase energy-saving appliances such as air conditioners and refrigerators. They also purchase solar panels and a wind generator. They choose the most desirable alternative with some attributes. These appliances have several attributes whose levels are changeable. As attributes, purchase prices (an initial cost), an annual electricity bill, subsidies, CO_2 emissions, stable electricity supply, and energy sources which generate electricity are adopted. These attributes and their levels will now be discussed.

[6] I refer to Louviere, Hensher and Swait (2000), Kuriyama and Shoji (2005), Tsuge, Kuriyama and Mitani (2011), and Kuriyama, Tsuge and Shoji (2013) for a conjoint analysis.

1. Purchase prices of energy-saving appliances (an initial cost)

Households purchase energy-saving appliances such as air conditioners and refrigerators, for example. In addition, they can purchase solar panels and a home micro-wind power generator. The purchase prices are 1, 1.5, or 2 million Japanese yen (JPY). The prices seem too expensive if households purchase only one air conditioner or refrigerator. But I assume that they purchase several appliances when they join an energy-saving program. They use these appliances for 10 years because in the feed-in-tariff system the procurement period of renewable energy for electric power companies is 10 years. When households don't purchase any energy-saving appliances, the initial cost is 0 JPY.

2. Annual electricity bill

If households purchase energy-saving appliances, they can save their annual electricity bill compared with current one. The levels are −50%, −30%, −10%, and 0% (unchanged). When they don't purchase any energy-saving appliances, their annual electricity bill is unchanged. When they purchase more expensive energy-saving appliances, they can reduce more annual electricity bill. Sometimes an annual electricity bill is unchanged even if households purchase energy-saving appliances. But CO_2 emissions are more reduced instead. When households generate electricity by solar and/or wind power, they can sell surplus electricity that they don't use to electric power companies and thereby gain income. The income from selling electricity depends on their surplus electricity and their electricity saving. This income is included in the reduction of their annual electricity expenditure. If households gain income by selling electricity, their annual electricity bill is reduced. The procurement period of solar power in fiscal year 2016 for residence and less than 10kW is 10 years.[7] Households can imagine long-term electricity saving by designating the period as "per year".

3. Subsidies

Sometimes, households receive subsidies from the governments when they purchase energy-saving appliances, solar panels, and wind generators. Households are supposed to earn some percentage of its purchase prices as a subsidy. The levels in the questionnaire are 0%, 10%, and 30%. 0% means that households don't get subsidies. Sometimes, households don't get subsidies even if they purchase energy-saving appliances. Such households may have a strong interest in these appliances. Of course, if households don't purchase these appliances, they don't get subsidies.

4. CO_2 emissions

If we use energy-saving appliances, we may reduce CO_2 emissions. If households have an interest in curbing global warming, they might purchase energy-saving appliances to reduce CO_2 emissions. CO_2 emissions are non-monetary factors. The levels are −20%, −10%, 0% (unchanged), and +10%. If fossil fuels are used in generation of electricity, sometimes CO_2 emissions may be unchanged or increase.

5. Stable electricity supply

When electricity is constantly supplied, no outages occur in a year. When electricity isn't constantly supplied, short-term outages may occur a few times in a year, or lights in houses may become dimmer. A dummy variable is used. It is assigned 1 for no outages and is assigned 0 for outages. When renewable energy is used, its electricity supply sometimes might not be stable due to weather conditions. When renewable energy isn't used, the electricity supply is always stable.

6. Main energy sources

Households use electricity when they use energy-saving appliances. The main energy source which is used in electricity generation is following: nuclear power, fossil fuels such as LNG, oil and coal, solar power, and wind power. The main energy source has the highest share in the composition of energy sources. A dummy variable is used for each energy source where fossil

[7] The procurement period for wind power is 20 years (the Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry). However, I assume 10 years for simplicity.

fuels is the base category. Households purchase electricity generated by nuclear power and fossil fuels from an existing electric power company or generate electricity by their own solar panels and a wind generator. When households don't purchase any energy-saving appliances, they use the energy source used by electric power companies in their area. In 2016, the main provided energy source was fossil fuels (LNG).

Respondents were informed of the questionnaire's purposes to facilitate data collection. Nuclear power plants ceased operation after the earthquake but plans to start them again are difficult to implement. More use of fossil fuels such as coal and oil, which emit CO_2, makes it difficult to avoid global warming. In these situations, renewable energy such as solar and wind power should be promoted urgently. At the same time, households need to reduce electricity usage. Table 1 summarized the levels of each variable.

Table 1 Levels of each variable

Variable	Level
Initial cost (million JPY)	1, 1.5, 2
Annual electricity bill	-50%, -30%, -10% and 0% (unchanged)
Subsidies	0%, 10%, 30%
CO_2 emissions	-20%, -10%, 0% (unchanged) and +10%
Stability	Yes (1), no (0)
Energy sources	nuclear power, fossil fuels, solar power, and wind power

Through the orthogonal planning method, I made profiles after deleting unrealistic and dominant cards. When households use nuclear power and renewable energy, CO_2 emissions are reduced. When households use nuclear power and fossil fuels, electricity is constantly supplied. When households purchase solar panels and a wind generator, the initial costs are 2 million JPY, but sometimes they can purchase them at 1 or 1.5 million JPY. One of the examples of unrealistic cards is that CO_2 emissions increase even though nuclear power or renewable energy is used. One of the examples of dominant cards is that an electricity bill is reduced, and an initial cost is very cheap even though renewable energy is used. Table 2 presents an example of profile.

Table 2 Example of profile

	Status quo	Program A	Program B
Initial cost (million yen)	0	1.5	2
Annual electricity bill	unchanged	-30%	-30%
Subsidies	0	10%	0
CO_2 emissions	unchanged	-20%	-30%
Stability	stable	stable	stable
Energy source	fossil fuels	nuclear	solar

Households choose the most desirable alternative. They answer with respect to 10 choice questions. Each question has various levels of attributes. The data were collected via a web-based questionnaire, utilizing the services of the Rakuten Research Company. The sample size is 750 households in Kanto[8], Kansai[9], and Chukyo[10] areas. In Kanto area households purchase electricity from the Tokyo electric power company (TEPCO) which has several nuclear power plants. They

[8] Tokyo, Chiba, Kanagawa and Saitama prefecture
[9] Osaka, Kyoto, Hyogo, Shiga and Nara prefecture
[10] Aichi, Gifu and Mie prefecture

experienced the planned outages after the earthquake. In Kansai area households purchase electricity from the Kansai electric power company (KEPCO) which also has several nuclear power plants. They didn't experience any planned outages but were requested to save electricity usage because the nuclear power plants stopped operation. In Chukyo area households purchase electricity from the Chubu electric power company (CEPCO) which has the Hamaoka nuclear power plant. CEPCO doesn't largely depend on nuclear power compared with TEPCO and KEPCO. The three areas are different in the dependence on nuclear power and are also different in households' preferences for energy-saving appliances. The sample is weighted by each area's population. Respondents' age is under 59 because these appliances are used for 10 years. Data were collected in February 2017. Table 3 shows the attributes of sample households. Respondents who are unemployed and whose income is less than 2,000 are more observed than the population.

Table 3 Socio-demographic attributes

		Number	%
	Total	750	100
Occupation	Employed	568	75.7
	Unemployed	182	24.3
Household income (thousand JPY)	Less than 2,000	209	27.9
	2,000-3,990	153	20.4
	4,000-5,990	173	23.1
	6,000-7,990	97	12.9
	8,000-9,990	48	6.4
	More than 10,000	70	9.3
Educational background	Junior high school, high school	203	27.1
	Technical school, junior college	173	23.1
	University, graduate school	374	49.9
Family composition	Single	151	20.1
	Couple	160	21.3
	Three	197	26.3
	Four	159	21.2
	Five	62	8.3
	More than six	21	2.8
Dwelling type	Detached house (including two households house)	363	48.4
	Collective housing (condominium, apartment, housing complex etc.)	355	47.3
	Company housing, dormitory housing etc.	32	4.3
Sex	Male	382	50.9
	Female	368	49.1
Age (years old)	20-29	154	20.5
	30-39	192	25.6
	40-49	227	30.3
	50-59	177	23.6
	Average	40.50	
	Minimum	20	
	Maximum	59	

In the questionnaire, I surveyed households' opinions and perceptions of energy problems.

54.3% households feel that electricity bill has become higher after the earthquake. 67.4% save electricity usage after the earthquake. 87.9% think they should reduce global greenhouse gases and only 12.2% think they don't need to reduce global greenhouse gases. On the most desirable future energy source, 37.7% think solar power is the most desirable energy source. On the other hand, only 19.5% think nuclear power is the most desirable energy source. 12.7% think LNG is the most desirable energy source. I also surveyed households' opinions and perceptions of energy-saving appliances. 38.8% have energy-saving air conditioners and 33.3% have energy-saving refrigerators. 53.6% don't have an interest in solar panels and 71.2% don't have an interest in a wind power generator.

4. Econometric analysis

4.1 Random parameter logit model

In a choice experiment, the dependent variable is discrete. To estimate the choice model, therefore, a discrete choice econometric model should be used. A conditional logit model is a popular model in this context. However, this model assumes an Independent and Identical Distribution (IID), and this assumption derives from the Independence of Irrelevant Alternatives (IIA). This assumption is restricted and easily violated in many cases. Consequently, a random parameter logit model (mixed logit model) is used as a general discrete choice econometric model. This model allows the random variation of individual preferences, unrestricted substitution patterns, and correlation among unobserved factors over time.[11]

A random parameter logit model assumes that each parameter has a specific distribution. The utility is specified as

$$U_{nj} = \alpha' x_{nj} + \beta_n' z_{nj} + \varepsilon_{nj}$$

This function specifies that individual *n* chooses alternative *j*, where α is non-random parameters and β_n is random parameters that represents the preference of each individual and varies among individuals. In this paper, constant terms and the parameter of annual electricity bill, which is a price parameter, are non-random parameters. x_{nj} is a variable vector that includes an annual electricity bill. On the other hand, the parameters of CO_2 emissions, a stable electricity supply, and energy sources are random parameters. The parameters of an initial cost and subsidies, which are monetary factors, are also random parameters. z_{nj} is a variable vector that includes the initial cost, subsidies, CO_2 emissions, a stable electricity supply, and energy sources. ε_{nj} is a random error term and has an IID extreme value.

The probability conditional on β_n is

$$L_{ni}(\beta_n) = \frac{\exp(\beta_n' x_{ni})}{\sum_j \exp(\beta_n' x_{nj})}$$

The random parameter logit probability is

$$P_{ni} = \int \left(\frac{\exp(\beta' x_{ni})}{\sum_j \exp(\beta' x_{nj})} \right) f(\beta) d\beta$$

This probability is the unconditional choice probability calculated as the integral of $L_{ni}(\beta_n)$ over all β_n.

The distribution of β_n must be assumed. Usually, a normal, lognormal, or triangular distribution,

[11] Train (2003) and Louviere et al. (2000) are referred for the explanation of a random parameter logit model.

etc., can be assumed. In this paper, a normal distribution is assumed.
Simulation methods were used for estimation. The simulated probability is

$$\widetilde{P_{ni}} = \frac{1}{R}\sum_{r=1}^{R} L_{ni}(\beta^{r})$$

where R is the number of draws. This simulated probability is an unbiased estimator of P_{ni}. The simulated log likelihood is

$$SSL = \sum_{n=1}^{N}\sum_{j=1}^{J} d_{nj}\ln\widetilde{P_{nj}}$$

where d_{nj} is an indicator. It equals 1 if individual *n* chooses alternative *j*, or is 0 otherwise. SSL was maximized to capture the maximum simulated likelihood estimator. In addition, 100 Halton draws were used for simulation. For estimation, *Limdep NLOGIT 5* was used.

4.2 Nested logit model

In the alternative 1, households don’t purchase any energy-saving appliances, while in the alternatives 2 and 3, they purchase energy-saving appliances. When respondents face these alternatives, they first choose to purchase energy-saving appliances or not. Then, if they decide to purchase, they choose better energy-saving appliances. Alternatives 2 and 3 are included in the same category or nest. A nested logit model is applicable. In a nested logit model, the cumulative distribution of error term ε_{nj} is assumed in following formula:

$$\exp\left(-\sum_{k=1}^{K}\left(\sum_{j\in B_k} e^{-\varepsilon_{nj}/\lambda_k}\right)^{\lambda_k}\right)$$

This distribution is a kind of generalized extreme value (GEV) distribution, where *K* is the number of nests and *k* is a nest number. Unobservable error term ε_{nj} is correlated among alternatives within a nest and isn’t correlated outside a nest. λ_k is a scale parameter that measures the correlation between error terms within a nest *k*. The higher the value, the lower the correlation is. When $\lambda_k = 1$, error terms aren’t correlated within the same nest. In a conditional logit model, all scale parameters between alternatives have the same value. The probability that individual n chooses alternative I is

$$P_{ni} = \frac{e^{V_{ni}/\lambda_k}\left(\sum_{j\in B_k} e^{V_{nj}/\lambda_k}\right)^{\lambda_k-1}}{\sum_{l=1}^{K}\left(\sum_{j\in B_l} e^{V_{nj}/\lambda_k}\right)^{\lambda_l}}$$

where V_{ni} is a deterministic term in a utility function. The maximum likelihood method is used for estimation. Using this choice probability, a likelihood function is formed, a log-likelihood function is maximized, and estimates are obtained. This choice probability can be written using this formula:

$$P_{ni} = P_{ni|B_k}P_{nB_k}$$

where $P_{ni|B_k}$ is a conditional probability that individual *n* chooses alternative *i* under the condition that individual *n* chooses an alternative within a nest; individual *n* chooses a nest *k*.

P_{nB_k} is the probability that individual n chooses an alternative within a nest k. This means that an individual chooses a nest and then chooses an alternative within the nest. P_{ni} is the product of a conditional probability and a marginal probability; these probabilities are written in the following formula:

$$P_{nB_k} = \frac{e^{W_{nk}+\lambda_k I_{nk}}}{\sum_{l=1}^{K} e^{W_{nl}+\lambda_l I_{nl}}}$$

$$P_{ni|B_k} = \frac{e^{Y_{ni}/\lambda_k}}{\sum_{j\in B_k} e^{Y_{ni}/\lambda_k}}$$

where W is a set of variables representing the attributes of a nest and Y is a set of variables representing the attributes of each alternative. I is called an inclusive value (IV) in a nest and is written as follows:

$$I_{nk} = \ln \sum_{j\in B_k} e^{Y_{ni}/\lambda_k}$$

In a nested logit model, IV parameters are estimated. IV is also called a log-sum variable or an expected maximum utility. IV parameters lie between 0 and 1. When all IV parameters are 1, the model is a conditional logit model. When an IV parameter is above 1, the structure of nest is not suitable. This means that the correlation between alternatives outside the nest is stronger than inside the nest.

In a nested logit model, scale parameters are normalized in upper or elemental nest level to 1. The upper nest level is “purchase” or “don’t purchase.” The elemental nest level is each alternative. Random utility model 1 (RU1) is the model where scale parameters in an elemental nest level are normalized to 1. Random utility model 2 (RU2) is the model where scale parameters in upper nest level are normalized to 1 and scale parameters in elemental nest level are free. RU2 is used in this paper.

5. The estimation results

In this section, I show the estimation results and discuss the preferences for energy-saving appliances. Firstly, I show the results of a random parameter model and a nested logit model from full sample. Next, I show the results from subsamples.

5.1 The estimation results

Table 4 expresses the choice number and choice probability for each alternative.

Table 4 Choice probability

	Alternative 1	Alternative 2	Alternative 3	total
Number	3488	1996	2016	7500
Choice probability	0.4651	0.2661	0.2688	1

The choice probability for Alternative 1 is the highest. However, more than 50 % households choose Alternative 2 or 3, which means that more than 50 % households are interested in energy-saving appliances.

Table 5 illustrates the estimation results of a random parameter logit model.

Table 5 Estimation results (random parameter logit model)

Variable	Coefficient	Standard Error	Z value	P value
Random parameter				
Initial cost	-0.01949	0.00224	-8.71	0.000
Subsidies	0.0087	0.0029	3	0.003
CO_2 emissions	-0.00719	0.00509	-1.41	0.158
Stability	0.69653	0.15348	4.54	0.000
Nuclear	-1.45308	0.19494	-7.45	0.000
Solar	1.41504	0.12036	11.76	0.000
Wind	1.0538	0.11644	9.05	0.000
Non- random parameter				
Electricity bill	-0.02263	0.00254	-8.92	0.000
Constant for alt 1	0.30977	0.42365	0.73	0.465
Constant for alt 2	0.91692	0.19293	4.75	0.000
Standard deviation				
Initial cost	0.03026	0.00134	22.67	0.000
Subsidies	0.0023	0.00598	0.38	0.701
CO_2 emissions	0.05223	0.00817	6.39	0.000
Stability	1.53834	0.12842	11.98	0.000
Nuclear	3.37602	0.22782	14.82	0.000
Solar	0.44555	0.17778	2.51	0.012
Wind	0.26066	0.1707	1.53	0.127
Log likelihood	-4688.76			
McFadden R^2	0.431			

Both the initial cost and annual electricity bill coefficients have a negative sign and are significant at the 1% level. If the initial cost and annual electricity bill are lower, households tend to purchase energy-saving appliances. The subsidies' coefficient has a positive sign and is significant at the 1% level. If subsidies are higher, households tend to purchase energy-saving appliances. These are monetary attributes. We find that households respond significantly to the monetary factors. On the other hand, the CO_2 emissions coefficient has a negative sign but isn't significant. Households don't respond to CO_2 emissions. Even if CO_2 emissions are reduced by energy-saving appliances, households don't purchase energy-saving appliances. The coefficient associated with stable electricity supply has a positive sign and is significant at the 1% level. Households value heavily stable electricity-supply in energy saving.

Next is the estimation results about energy sources. Dummy variables for each energy source are used, with fossil fuels as the base category. The nuclear power coefficient has a negative sign and is significant at the 1% level. If the electricity is generated by nuclear power instead of fossil fuels, households don't purchase energy-saving appliances. On the other hand, the coefficient associated with renewable energy, both solar and wind power, has a positive sign and is significant at the 1% level. If the electricity is generated by renewable energy sources instead of fossil fuels, households might purchase energy-saving appliances. Or households have a potential to invest solar panels and a wind generator.

From the results, households respond to the monetary factors. For the promotion of energy-saving appliances, the initial cost and annual electricity bill should be lower, and subsidies should be higher. Moreover, the electricity should be supplied constantly. By using electricity generated by renewable energy, households might purchase energy-saving appliances. These results indicate that renewable energy and energy-saving appliances can be promoted simultaneously.

The constant term for Alternative 2 is positive and significant at the 1% level. Households tend to purchase energy-saving appliances regardless of their attribute levels. The standard deviation of random parameters expresses the variations in households' preferences. Almost all attributes except subsidies are significant. The preferences vary among households whereas the preferences for subsidies are similar.

I tried the estimation by a nested logit model because the alternatives have a nest structure. Alternative 1 is "don't purchase", while Alternatives 2 and 3 are "purchase". This choice set has a nest structure where Alternatives 2 and 3 are within the same category as "purchase". Households choose "purchase" or "don't purchase" at the first stage, and then they choose Program A or Program B at the next stage if they choose "purchase." Random utility model 2 (RU2) is used where a scale parameter in the upper level whose alternative is "purchase" or "don't purchase" is normalized to 1, while a scale parameter in the lower level which is each alternative is free. Table 6 shows the estimation results.

Table 6 Estimation results (nested logit model)

Variable	Coefficient	Standard Error	Z value	P value
Initial cost	-0.0022	0.0009	-2.54	0.011
Annual electricity bill	-0.0056	0.0012	-4.64	0.000
Subsidies	0.0042	0.0013	3.32	0.001
CO_2 emissions	-0.0027	0.0020	-1.36	0.172
Stability	0.1714	0.0536	3.2	0.001
Nuclear	-0.1530	0.0488	-3.13	0.002
Solar	0.4088	0.0919	4.45	0.000
Wind	0.3594	0.0848	4.24	0.000
Constant for alt 1	0.2401	0.2091	1.15	0.251
Constant for alt 2	0.0369	0.0761	0.48	0.628
IV parameter				
Don't purchase	1			
Purchase	0.4476	0.0955	4.69	0.000
Log likelihood	-7600.53			
McFadden R^2	0.048			

The estimation results are almost the same as the results of a random parameter logit model. The IV parameter is significant at 1% level. Moreover, the value is between 0 and 1, indicating that the nest structure is suitable. Alternative 1, which is "don't purchase," and Alternatives 2 and 3, which are "purchase," don't have substitution. Alternatives 2 and 3 have a strong substitution. Households choose "purchase" or "don't purchase" in the first stage, and then they choose Program A or Program B in the next stage. McFadden R^2 is much smaller than that of a random parameter logit model. To explain the households' purchase of energy-saving appliances, a random parameter logit model is superior to a nested logit model.

5.2 Differences across households' socio-demographic attributes

I asked households about their socio-demographic attributes and perceptions of energy problems in the questionnaire. I examine the differences of purchase behavior for energy-saving appliances across households' socio-demographic attributes and perceptions. I divided the sample into two subsamples to balance the sample size in two subsamples. Table 7 is the list of subsamples. I use a dummy variable for each subsample. I assign 1 or 0 for each subsample. I show the assignment in table 7.

Table 7 List of subsamples

Attributes	Subsamples (dummy variable)	Definition	Sample size
Household income	Low income (0)	Under 4 million JPY	362
	High income (1)	More than 4 million JPY	388
Family composition	Small family (0)	Single and couple family	311
	Big family (1)	Married parents and unmarried children family, and more than two adult generations family	439
Residential type	Detached house (1)	Detached house (two household houses are included)	363
	Collective house (0)	Condominium, apartment, housing complex and a company and dormitory housing	387
Living area	Kanto (1)	Households who live in Kanto area	435
	Chukyo (0)	Households who live in Chukyo area	114
	Kansai (0)	Households who live in Kansai area	201
Age	Young age (1)	Less than 39 years old (average)	346
	Old age (0)	More than 40 years old	404
Perception of electricity bill	High bill (1)	Households who think electricity bill is higher after the earthquake	407
	Low bill (0)	Households who don't think electricity bill is higher after the earthquake	343
Perception of energy-saving	Save (1)	Households who save electricity usage after the earthquake	506
	Don't save (0)	Households who don't save electricity usage after the earthquake	244
Desirable energy source	Renewable energy (1)	Households who prefer renewable energy	483
	Non-renewable energy (0)	Households who prefer non- renewable energy	267

I use the cross terms of each independent variable and each dummy variable to examine the differences. Table 8 expresses the estimation results. A random parameter logit model is used for estimation.

Table 8 The estimation results with cross terms

	Household income		Family composition		Residential type		Living area	
Initial cost	-0.016	***	-0.019	***	-0.019	***	-0.020	***
Subsidies	0.009	**	0.007		0.010	***	0.005	
CO_2 emissions	-0.006		-0.010		-0.009		-0.004	
Stability	0.686	***	0.684	***	0.612	***	0.603	**
Nuclear	-1.955	***	-1.658	***	-1.576	***	-2.186	***
Solar	1.350	***	1.317	***	1.285	***	1.172	***
Wind	1.044	***	1.103	***	0.959	***	0.840	***
Annual electricity	-0.025	***	-0.019	***	-0.020	***	-0.024	***

bill								
Cross term								
Initial cost	0.002		0.000		-0.001		0.001	
Annual electricity bill	0.002		-0.006		-0.006		0.002	
Subsidies	-0.004		0.003		-0.003		0.003	
CO_2 emissions	-0.007		0.005		0.004		-0.008	
Stability	0.134		0.030		0.160		0.211	
Nuclear	0.682	**	0.272		0.232		1.016	***
Solar	0.029		0.157		0.260		0.291	
Wind	0.034		-0.086		0.192		0.331	
Constant for alt 1	0.463		0.314		0.305		0.396	
Constant for alt 2	1.037	***	0.922	***	0.919	***	1.016	***
McFadden R^2	0.433		0.431		0.431		0.432	
	Age		Perception of electricity bill		Perception of energy-saving		Desirable energy source	
Initial cost	-0.015	***	-0.026	***	-0.022	***	-0.023	***
Subsidies	0.007	*	0.012	***	0.006		0.001	
CO_2 emissions	-0.008		-0.014	*	-0.020	**	-0.011	
Stability	0.826	***	1.013	***	1.210	***	0.864	***
Nuclear	-1.770	***	-1.702	***	-1.794	***	-0.384	
Solar	1.653	***	1.749	***	1.210	***	0.722	***
Wind	1.419	***	1.205	***	0.947	***	0.454	**
Annual electricity bill	-0.023	***	-0.018	***	-0.021	***	-0.015	***
Cross term								
Initial cost	0.002		0.009	***	0.007	***	0.010	***
Annual electricity bill	0.001		-0.009	**	-0.004		-0.015	***
Subsidies	-0.001		-0.007		0.002		0.009	*
CO_2 emissions	-0.004		0.009		0.015		0.004	
Stability	-0.255		-0.548	*	-0.646	**	-0.238	
Nuclear	0.302		0.251		0.407		-1.857	***
Solar	-0.508	**	-0.587	**	0.208		1.011	***
Wind	-0.780	***	-0.265		0.134		0.865	***
Constant for alt 1	0.411		0.310		0.528		0.429	
Constant for alt 2	1.000	***	0.937	***	1.077	***	1.028	***
McFadden R^2	0.435		0.432		0.433		0.441	

Note) *** 1%, ** 5%, *10% significant level

There is no significant cross term in family composition and residential type. We don't observe any differences in family composition and residential type. Higher income households positively evaluate nuclear power. Households who live in Kanto area also positively evaluate nuclear power even though they suffered from serious accidents of nuclear power plants in Fukushima. Younger households don't evaluate renewable energy than older ones. Households who think electricity bill is higher after the earthquake give less evaluation for a stable electricity supply and solar power. They accept higher initial cost and prefer a lower annual electricity bill. Households who save electricity usage after the earthquake also accept higher initial cost and give less evaluation for a stable electricity supply. Only older households purchase energy-saving appliances when renewable energy is used in electricity generation.

Next, I examine the differences between households who support renewable energy as the most desirable one and ones who support non-renewable energy. I asked households the most desirable energy source in the future in the questionnaire. Renewable energy sources include solar, wind, geothermal, biomass and hydraulic power, while non-renewable energy sources include nuclear, coal and natural gas. One of the aims of this paper is to examine the relation between preferences for renewable energy and purchase of energy-saving appliances. Households who prefer renewable energy may purchase energy-saving appliances. From the estimation results, households who support renewable energy positively evaluate a lower annual electricity bill, a stable electricity supply and solar and wind power. They accept higher initial cost and negatively evaluate nuclear power. When renewable energy is used in electricity generation, households who support renewable energy may purchase energy-saving appliances.

Parameter differences are tested to examine that purchase behavior of energy-saving appliances is different or not between two subsamples. For the parameter differences test, the likelihood test and the following test statistic are used.

$$-2[LL(A+B) - (LL(A)+LL(B))]$$

LL(A+B) is the log likelihood which is obtained after estimation by pooling data from two subsamples. LL(A) and LL(B) are the log likelihoods for each subsample. The null hypothesis is that parameters or behavior between two subsamples are equal. The alternative hypothesis is that parameters or behavior are not equal. The test statistic is chi-squared distributed with degrees of freedom equal to the number of parameters. The critical values for 1%, 5% and 10% significance level are respectively 33.41, 27.59 and 24.77 for 17 degrees of freedom. Table 9 expresses the results of the parameter differences test. If calculated statistic is inside the rejection area, the null hypothesis is rejected. Parameters between two subsamples are, thus, significantly different and households in two subsamples show different behavior.

Table 9 Results of the parameter differences test

	test statistics		
Household income	14.431		same
Family composition	16.588		same
Residential type	21.370		same
Living area	19.517		same
Age	67.242	***	different
Perception of electricity bill	47.724	***	different
Perception of energy-saving	89.814	***	different
Desirable energy source	182.060	***	different

Note) *** 1%, ** 5%, *10% significant level

In household income, family composition, residential type and living area, we don’t observe the significant differences between two subsamples. However, we observe the differences between younger and older generation. In all items about perceptions, we observe the differences between two subsamples.

6. Conclusions and policy implications

In Japan after the earthquake, the prevalence of energy-saving appliances including solar panels and wind generators and renewable energy such as solar and wind power is urgent and essential topic. I analyzed the conditions that households purchase energy-saving appliances through a conjoint analysis. I included an annual electricity bill, an initial cost and subsidies as monetary factors, and CO_2 emissions, stability of electricity supply and main energy sources as non-monetary factors. The estimation results indicated that households largely respond to monetary factors. If an annual electricity bill is reduced, initial cost is cheaper, and subsidies increase, households might purchase energy-saving appliances. To promote energy-saving appliances, it is necessary to reduce an electricity bill and an initial cost and to raise subsidies.

Households also need stable electricity supply, but they don’t show any interests to reduce CO_2 emissions.

Especially, I focus on the role of renewable energy as an energy source in generation of electricity when households purchase energy-saving appliances. We found that if the main energy source is renewable energy households might purchase energy-saving appliances. The findings also say that households have their strong interest in solar panels and wind generators. By utilizing households’ preferences for renewable energy, energy-saving appliances will be promoted. These results indicate that renewable energy and energy-saving appliances can be promoted simultaneously.

If households show high evaluation for renewable energy, it is possible to promote energy-saving appliances by appealing to their interest in renewable energy. However, electricity generated by solar and wind power depends on the weather conditions. Storage batteries is needed therefore to ensure a stable electricity supply.

Free-riding is another serious problem arising in long-term energy efficiency. For example, CO_2 emissions can be solved by other people’s efforts, so an individual might not have an incentive to purchase energy-saving appliances. To promote energy-efficient appliances, the governments should offer subsidies to each household. But, households have a strong interest in renewable energy and they might decide to purchase energy efficient appliances without subsidies.

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